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ABSTRACT

A review was made of current practices, problems, and related efforts to improve public education. It showed that teachers have been asked to perform an impossible instructional task, and to improve public education a systematic study of the important relevant variables must be initiated. These findings need to be implemented in systematic instructional programs which draw on advanced knowledge of curriculum, instructional methodology, learner variables, and instructional delivery systems. However, psychological research evidence is not directly applicable to the nonlaboratory learning situations in schools. Also, there is little, if any, established data about teaching which is widely accepted. On the other hand, the recognition of trait-treatment interaction analysis is an important milestone despite current criticisms. In addition, computer generated instructional materials have been quite positive when compared to traditional instruction. Programatic research efforts will be required to identify the appropriate variables and relationships and incorporate them into a single adaptive interactive instructional system which can have widespread application. (WCM)

EDUCATIONAL TECHNOLOGY ANNUAL REVIEW: ADAPTIVE INTERACTIVE INSTRUCTIONAL SYSTEMS FOR EDUCATION

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> "The era of instruction that will supersede the era of human based instruction is to be one of man-machine interaction. And the machine is the computer. We have lived in the shadow of the computer long enough now but used it so little in instructional affairs that we may be inclined to believe its future and ours to be things apart. Nothing can be farther from the truth." (Goodlad, 1968, p. 7)

Overview

The purpose of this paper is to review the current practices, problems, and related efforts to improve public education and propose alternative procedures for better meeting the educational needs of children in the United States. The instructional setting has grown from that of a tutor working with a few sons of the local aristocracy--teaching and learning together about the important literature of their day--to the present instructional setting of the teacher and thirty pupils teaching and learning about the content of the universe and beyond. What was once a well balanced educational system has long since become a lopsided system causing extreme frustration in all corners of the arena. Boards of public education are spending large amounts of money to provide education to the nation's children, when at the present time there may be alternative expenditures which would improve the quality of education. Evidence exists to show that even the most rudimentary adaptive interactive instructional systems available today will meet some of the needs

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of the learners, teachers, and society. Additional research and development are needed to expand the limited knowledge and apply such systems to a large portion of public education. This paper will review the related factors, research efforts which have been made to improve education, and propose a model or strategy for further research and development which holds promise for drastically improving education.

Current Practices and Problems in Public Education

A number of critiques (Holt, 1964; Kozol, 1967; and Silberman, 1970) document the existance of a crisis in public education. Mitzel (1972) identified four factors involved in this crisis: 1) lack of confidence between the lay public and educators, 2) lack of confidence between education workers and boards of control, 3) rising school costs, and 4) poor student achievement caused by deteriorating pupil/teacher relations. The crisis is substantiated by school statistics on excessive absences, vandalism, drug abuse, riots, and violent attacks on authority figures (Mitzel, 1972; The National Observer, July 12, 1973). The common element (explicit or implied) in each of these factors is people--usually the classroom teacher, e.g., if a child is not progressing satisfactorially the parent questions the teacher's skills and ability; collective bargaining has cast school boards and classroom teachers into new adversary roles; and since a large portion of the schools' budgets are spent for salaries, rising labor costs mean increased expenditures.

Parents, school board members, superintendents, and classroom teachers all know much more about how to educate children then they are able to implement with the existing teaching, administrative and organizational constraints. Evaluation studies which indicate that teachers are ineffective are not at all surprising if we examine the processes which have brought us to our present day practices in education. When education was the province of the rich, a tutor was employed to provide education and instruction to the young sons of the aristocracy. The tutor provided information, remedial feedback, corrective information, and approval to the responses made by the learner. The knowledge and experience of the tutor was conveyed to the learners interactively. Eventually instruction

was transferred to printed texts as printing technology became available. The tutoring system worked well and when it became desirable for more and more individuals to experience learning and education the natural step was to assign more learners to the tutors. Since even then education was not available to everyone, the student population was small in number and tutors were able to function quite well.

In contrast today, education is for everyone and therefore the variability among students has increased. In a similar manner there is more knowledge and information which school children are expected to learn and the curriculum has therefore expanded. The one element which has not changed in the instructional system however is the teacher or the "interactive instructional processor." Why should we expect an instructional system composed of a tutor, a learner, and a limited curriculum to transfer directly from antiquity to today's instructional setting where all parameters have changed except the capabilities of the tutor? Teachers have been bombarded with demands to expand the curriculum, use new instructional methods and media according to the latest research findings, and adapt to the individual differences of thirty learners simultaneously. We have in essence asked teachers to perform an impossible instructional task!

Efforts to Improve Current Practices

During the last forty years the number of full-time employees in education has grown twice as fast as the number of students and more than three times as fast as the population (Haggerty, 1973) with no evidence of increased productivity measured by increased student performance (Rosenshine, 1970). Although it is obvious that public schools are investing their dollars (and therefore their trust) in teachers, reviews of research on teaching do not provide evidence that the trust is warranted. Averch, et al. (1972) reviewed studies funded by the U. S. Office of Education for the purpose of determining what does and what does not improve instruction. Their review suggested two major implications for school finance: 1) "increasing expenditures on traditional educational practices is not likely to improve educational outcomes substantially (p. 155)," and 2) "there seem to be opportunities for significant reduction or redirection of educational expenditures without deterioration in educational outcomes (p. 155)."

Their review tentatively suggests that "improvement in student outcomes, both cognitive and noncognitive, may require sweeping changes in the organization, structure, and conduct of educational experience (p. 158)."

The U. S. Office of Education and the National Institute of Education have been very active in attempting to improve education by supporting research efforts and innovative practices which hold promise for improving public education within the given constructs and structure of every day school life. The most common techniques employed in these projects were to provide: 1) smaller classes; 2) additional personnel; 3) individualized instruction; and 4) audio-visual equipment (Averch, 1972). These practices resulted in no significant improvement in student performance. Although the first three categories all imply more personnel in the instructional process, it is interesting to note that Rosenshine (1970) in a critical review of nine studies of teacher effectiveness found that teachers are not generally stable in teaching effectiveness when presenting the same material over time, nor does their effectiveness appear to generalize over topics. The continued reliance on teachers to provide the major thrust of the educational experiences for children is of dubious merit. Instructional programs which rely on individuals for their continued success and conduct will without doubt be modified, redirected, or lost completely when the teaching personnel is replaced by other individuals (Washburne, 1925 and Dean, 1943).

To make significant progress in the improvement of public education in the United States a systematic study of the important relevant variables must be initiated and the findings implemented in systematic instructional programs which draw upon the most advanced knowledge of curriculum, instructional methodology, learner variables, and instructional delivery systems. Sufficient knowledge and technology is available to begin such an effort although additional research and development will be required to carry the development to the highest levels possible with existing and "near future" technology.

Review of Research on Improving Instruction

A study of the current research literature on the instructional process indicates that much effort has been focused in three categories: 1) presentation or treatment variables; 2) learner variables; and 3) content variables. More

recently trait-by-treatment interaction analyses have been used as a summary paradigm for considering how the three categories of instructional variables interact in instruction. A brief review of these independent lines of research will make clear the limitation of such efforts.

Presentation or Treatment Variables

Instructional media research has focused on two main objectives: 1) to justify the inclusion of media of a particular type in some relatively ill-defined larger system; and 2) showing to some extent what kind and quantity of impact a given piece of instructional material may make (VanderMeer, 1964). The instructional media research prior to 1950 was characterized by a pre-occupation with "evaluative" comparison--learning from some unspecified film or medium was compared with learning from some unspecified presentation by an instructor or other medium (Allen, 1971). The review of audio visual research by Campeau (1967) reflects the perceived structure of the discipline and the nature of the important research questions in the past. The review is structured by media (television, motion pictures, programmed instruction, filmstrips, slides, transparencies and other pictorial presentations, radio and recording, three dimensional models, and field trips) and summarizes the research in these categories according to the nature of the investigation (comparative effectiveness studies, utilization studies, and basic studies). These studies have largely ignored the interaction of learning task, stimulus characteristics, and learner variables. Further it should be noted that these early studies focused on that portion of the instructional paradigm which could be "captured", preserved, and transmitted to other users--namely the stimulus materials. For example, the visual materials which are incorported in a set of 2 x 2 slides can be carefully analyzed and produced according to all known principles of graphic presentation.

In a similar fashion, an author and publisher can very carefully prepare the material for a textbook in a logical sequence but this does not prevent the learner or the mediator of the learning (the teacher) from changing the order based upon subjective opinions or judgments. It is interesting to note that many educators were surprised and shocked at the advent of programmed instruction when an author presumed that all learners could learn from a single presentational sequence for a given content area. We still continue this presumption by

preparing linear educational films, lectures, educational filmstrips, and other linear stimulus presentation materials. Some investigators (Saettler, 1968; Cooney and Allen, 1964; and Wagner, 1966) have experimented with alternative sequencing of materials to compensate for differing learner characteristics and differing instructor characteristics. At the time of the studies though technology was not readily available to provide non-linear presentations to learners as a general practice outside the experimental laboratory. However the recognition of the significance of the problem was an important milestone.

Learner Variables

DiVesta (1974) stated that the improvement of instruction during the 1970's will come from the aim of "adapting education to the child (p. 358)." Specifically he suggested that a primary educational objective must be to promote optimal cognitive development. This position is supported by the work of Lesser, 1972; Gagne and Gropper, 1965; Cronbach and Snow, 1969; and DiVesta, et al., 1970 and 1971abc. Many attempts to account for individual learner variables have sought ways to adapt group methods of instruction so that all children in the group progress at an acceptable rate and reach satisfactory levels of achievement in reasonable amounts of time. In both research and classroom practice the attempts to find ways to meet individual needs by group methods tend to encounter confusion of three important parts of the problem: 1) criteria; 2) learning variables; and 3) methods (Briggs, 1968).

The definition and classification of individual differences which are important for research is not an easy task. Powell (1971) identified the following dimensions of individual differences: chronological age, growth age, sex, intelligence, cognitive abilities, cognitive styles, interests, cultural background, and reading achievements. Berman (1973) produced a similar list of characteristics but divided them into three categories according to the difficulty with which the measure of that variable can be attained--e.g. easy measures to obtain included age, sex, grade level, and test scores; moderately difficult measures to obtain included educational background, interests andd hobbies, academic preference, vocational preference, etc.; and difficult measures to obtain included cultural background and history of relationship to the instructor.

Lesser (1972) cited numerous research studies dealing with instructional style and learning performance, however, without developing a structure of the field. Shumsky (1972) identified individual differences in learning style although Briggs (1968) conjectured that learning or cognitive style variables were relatively unimportant. Gagne (1964) indicated that most of the learning variance would be accounted for if one were to design media to adapt to the individual learner's general ability, special aptitudes, and entering competencies.

Curriculum Development Technology

It would appear that a great deal of evidence should be available to guide us in the development of curriculum materials for effective and efficient learning. The research literature in psychology abounds with studies on various kinds of learning tasks (e.g., paired-associate learning, concept acquisition, concept development and discrimination learning) with a variety of instructional strategies to examine the effect on immediate learning and retention. However these studies are not directly applicable to non-laboratory learning situtations because the experimenters have carefully isolated specific learning tasks and specific treatments to meet the needs of research paradigms (DiVesta, 1973). The school learning tasks of a first grade child cannot clearly and conveniently be segregated into such neat categories. More generally school learning tasks are combinations of such categories and therefore resist the direct application of findings from the psychological laboratory.

A great deal of effort has recently gone into curriculum development primarily in the field of science and mathematics under the sponsorship of the U. S. Office of Education, the National Science Foundation, and professional associations concerned with science education (Lockard, 1970). These efforts, successful as they may be in combining the expertise of scientists and educators in structuring new curricula at various grade levels, have far out-stripped the available instructional delivery systems -- teachers. Granted that teachers have been supported by training institutes and teachers' handbooks, the evidence suggests that the conundrum of the new curriculums is the reliance on teachers for implementation (Romey, 1973; Doll, 1964).

Efforts in the sequencing and the development of curriculum materials (Briggs, 1968; Davies, 1973; and Gagne and Gropper, 1965) have been hampered by the capability of preserving only the stimulus portion of the curriculum with very little control (if any) over the implementation of the curriculum outside of the research and development laboratory. Recent attempts to use digital computers to store and present stimulus materials to learners, receive and evaluate student responses, present evaluative feedback to learners and alter the flow and sequence of instruction according to student performance has opened new vistas for the empirical development of curriculum. Predesigned, as compared to "extemporaneous" (Gagne, 1967), instructional interactions allow for the careful study and analysis of variables relevant to improved instruction and learning.

Several different global tacks have already been taken in applying computer technology to curriculum development. Each different tack has been based on differing assumptions about the structure of knowledge and the implications of that difference for teaching that knowledge to learners. The work of Cartwright and Mitzel (1971) was guided by the decision that there would be no one instructional strategy employed throughout the course, but rather each author would intuitively employ the strategy he felt most useful for the particular content and learning objectives with which he was dealing. A somewhat narrower viewpoint was adopted by Birtch, Jordan, and Romaniuk (1969) with the assumption that a small number of differing instructional strategies or paradigms could be employed in teaching a variety of different content. The work of Merrill (1973) is couched on the assumption that content structure and instructional procedure are completely independent. His work has focused on establishing a core of information in computer storage and providing the student with controls for selectively moving through the material at his own discretion. Still another approach (Uttal, et al., 1970) focused on the power of the computer to generate curriculum materials in analytic geometry once certain instructional paradigms and algorithms were stored in the system. Since the cost of developing CAI courses is relatively high generative systems and automated systems of curriculum development have great appeal. However, as yet, they also appear to be somewhat limited in the kinds of curriculum that can be built using these techniques. The courses developed by Cartwright and Mitzel (1971) and Cartwright and Cartwright (1974) have been used successfully by over 5,000 pre-service and inservice teachers throughout the United States, but data is not yet available on the techniques used by Merrill which are still under development.

Additional research is required on the structure of knowledge bases, instructional strategies, and the interaction of both domains with the goal of providing individually adaptive interactive learning experiences on current topics to vast numbers of learners. However learner reactions to computer generated instructional materials have been quite positive (Hall, Adams, and Tardibuono, 1968) when compared to traditional instruction.

Trait-Treatment Interactions

Cronbach (1957) identified an area of research which in his opinion held much potential for the improvement of education:

> "Applied psychologists should deal with treatment and persons simultaneously. Treatments are characterized by many dimensions; so are persons. The two sets of dimensions together determine a payoff surface . . . We should design treatments, not to fit the average person, but to fit groups of students with particular aptitude patterns. Conversely, we should seek out the aptitudes which correspond to (interact with) modifiable aspects of the treatment (p. 672)."

This approach formalizes the efforts which many classroom teachers have been making in their daily teaching activities--providing differential instruction to different students--trait-treatment interactions (TTI). The concept is further explicated by Bracht and Glass, 1972; Rhetts, 1972; and Snow and Saloman, 1968; and Berliner and Cahen, 1973. Snow and Salomon (1968) reviewed research studies which originally had not been intended as studies of TTI but which showed that interaction in the data analysis. Their review of literature indicated that potential interactions are likely to reside in three classes of aptitude variables: 1) specific intellectual abilities like those defined in the work of Guilford (1967); 2) specific personality traits like those defined in the work of Cattell (1959); and 3) aptitudes in a poorly defined group of cognitive styles and preferences, learning sets, information processing and coding strategies, and other subtle experimental variables. The DiVesta (1973) and the Snow and Salomon (1968) articles are highly recommended for those wanting to pursue the concept of trait-treatment interaction effect on learning.

Other researchers have expressed reservations about the potency of trait-treatment interaction research. Hickey (1973) in a series of interviews to define research guidelines for computer-assisted instruction reported that

several researchers in CAI (Carroll, Gagne, Mitzel, Stolurow, and Suppes) all stated that the TTI research gives little cause for optimism. The lack of enthusiasm focused on the lack of demonstrated difference between treatments (Carroll and Suppes) and the conceptually mixed or impure nature of traditional aptitude testing (Gagne and Stolurow). However, DiVesta (1973) after reviewing recent TTI research identified the need to include the dynamic relations among situations, traits, processes, and outcomes rather than just the input-output relations emphasized in the current research literature.

Adaptive Interactive Instructional Systems for Education

During the past decade with the availability of sophisticated technology many attempts have been made to improve education by mimicking the attributes of a good tutor and implementing the results through computers. Through this work the appearance of such phrases as "individualized instruction", "instructional interaction", "adaptive teaching systems", and "adaptive interactions" have come into the education literature. Clark (1972) stated "individualized instruction should imply the matching of knowledge about student abilities and aptitudes with teaching materials designed or selected to improve their performance and confidence (p. 31)." Resnick (1972) defined instructional interactions as "any episode in which a learner becomes engaged with a person or with things (books, computers, games, programs, etc.) that have the capacity to teach, i.e., to change his performance capabilities in ways that are lasting (p. 70)."

Before the development of digital computers humans were the only mechanisms available which were capable of providing individualized instruction as defined by Clark and instructional interactions as defined by Resnick. Computer technology has made it possible to define complex sequences of interactive instructional events, program them for repeated use with individual learners and in essence simulate the interactions between a learner and a sophisticated tutor. Early efforts at harnessing computer technology and flexibility to provide individualized instructional interactions produced very successful results with specially built equipment for learning specific psychomotor skills (Lewis and Pask, 1965; and Uttal, et al., 1970). General purpose student stations have since been

developed and have provided opportunities to demonstrate the potentials of automating certain aspects of education. A review of CAI studies by Vinsonhaler and Bass (1971), which focused on drill and practice in language arts and math at the elementary school level consistantly showed superior performance for CAI students when compared with students receiving similar practice through conventional instructional techniques.

A review of thirteen CAI evaluative studies (Hall, 1974) reported on the performance of 11,877 students with 7,266 of them receiving instruction through computers and 4,611 of the students receiving conventional instruction.[1] A wide variety of students (low elementary level through post-high school, military training, and post-baccalauerate inservice teachers) and subject matter (elementary mathematics and reading, post-high school electronics maintenance and theory, college level Russian, and teacher education) were included in the studies. Instructional paradigms included drill and practice, tutorial and remediation. A consistent finding through all of these studies was that CAI produced at least as much learning as conventional instruction and in most cases produced more learning than conventional instruction. Considerable savings in time was also shown where this variable was investigated. Although direct comparison between studies was difficult because of the differing objectives, student characteristics, and content characteristics, there appeared to be an increase in learner performance caused by CAI in every instance. My judgment is that the primary factors causing improved learner performance were consistent with the factors associated with teacher effectiveness.

Averch, et al. (1972) found that smaller classes, additional personnel, individualized instruction and traditional audio visual equipment did not produce significant differences in pupil performance. Rosenshine (1970) found that teachers were not generally stable in teaching effectiveness in presenting the same material over time, nor did their effectiveness appear to generalize to other topics. However, Gordon (1971) found that a

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[1] These studies included Abramson, et al., 1970; Atkinson, 1968; Cartwright, Cartwright, and Robine, 1972; Ford and Slough, 1970; Hall and Mitzel, 1974; Harless, et al., 1969; Hurlock, 1971; Longo, 1969; Pagen and Arnold, 1970; Robinson and Lautenschlager, 1971; Seriven, 1970; and Suppes and Morningstar, 1969.

> "...tightly structured programed approach including frequent and immediate feedback to the pupil, combined with a tutorial relationship, individual pacing, and somewhat individualized programming are positively associated with accelerated pupil achievement (p. 24)."

Rosenshine and Furst (1971) found eleven kinds of teacher behavior significantly correlated with achievement scores. Five which were strongly supported by research include: 1) clarity of presentation, 2) variability of classroom activities, 3) enthusiasm, 4) degree to which the instruction was task or achievement-oriented or business-like, and 5) student opportunity to learn criterion material.

Because of the lack of evidence of consistent teacher effectiveness, we should consider the factors which have been found to be positively correlated with pupil achievement and determine which of these can be implemented without relying on the teacher for implementation. Summarizing the research produces the following attributes which should be included in the instructional environment: 1) frequent and immediate feedback to pupils, 2) tutorial relationship, 3) individual pacing, 4) individualized programing, 5) clarity of presentation, 6) motivational factors, 7) variability in classroom activities, 8) enthusiam, 9) degree to which instruction was task or achievement-oriented or business like, and 10) student opportunity to learn criterion material.

Glaser (1972) summarized the desirable characteristics of an educational system as follows:

> "The kinds of educational systems that we can consider most desirable will be drawn only from the fullest possible understanding of human behavior and from sustained carefully studied educational innovations with a flexibility for successive incremental improvement (p. 8)."

It is apparent to me at least that improvement in instruction will not come about through the efforts of researchers focused exclusively on treatment variables, learner variables, curriculum development technology, or trait-treatment interactions as singular entities or factors when much of the research on teaching effectiveness indicates the need for "real-time" adaptations to meet the individual needs of learners. Computers allow us to store and present stimulus materials to learners, receive and evaluate student responses, present evaluative feedback to learners and alter the flow and sequence of instruction

according to student performance (very much the same as live tutors) but with the added advantages of recording and/or replicating the exact sequence of instruction without variation for careful scrutiny and analysis. The capability the computer gives us to "capture" the instructional interactions of tutorial instruction for repeated use with students, analysis, and refinement gives us the data and "flexibility for successive incremental improvement" identified by Glaser (1972, p. 8). The capability of capturing tutorial interactions for individualized, repeated use with other students increases the importance of past research on teaching effectiveness.

Research on Teaching

Nuthall and Snook (1973) observed that the guiding force of research on teaching has not been the discovery and systematic accumulation of knowledge, but rather has been generated by debate and controversy over certain highly provocative pedagogical concepts and claims about how teaching ought to be viewed. They identified three dominant models which unlike models in the physical sciences, do not compete with each other as alternative views of the same bodies of established data. There is probably little, if any, established data about teaching which is widely accepted. Rather each model is fundamentally a claim about how teaching ought to be understood and interpreted and competes with the others as alternative ways of viewing the practical activity of teaching. The observations of Nuthall and Snook are supported by the inclusion of chapters in the "Handbook of Research on Teaching," (Gage, 1963) and the "Second Handbook on Research on Teaching," (Travers, 1973) on research in specific school subjects and specific grade levels, i.e., language arts, natural science, elementary school mathematics, secondary school mathematics, visual arts, physical education, social studies, business, foreign language, vocational skills, and college and university level or higher education depending on the edition of the handbook. Are these the important variables to examine to advance our knowledge about instruction and learning? Probably not! The growing bodies of knowledge cited earlier in this review about treatment variables, learner variables, curriculum development, and trait-by-treatment interactions, plus the availability of adaptive interactive instructional systems all argue that the time for piecemeal subject matter specific research is past and that a

more scientific approach toward the development of a data base and knowledge about teaching and learning is appropriate.

A great deal has been written about paradigms for research on teaching (Gage, 1963); contemporary models of teaching (Nuthall and Snook, 1973); theory construction for research on teaching (Snow, 1973); learning theory, educational media, and individualized instruction (Gagne, 1971); and adaptive machines for learning (Starkweather, 1970). The research has focused on a variety of phases of the instructional process but most consistently not on the interactive phase of instruction which takes place between a tutor and a learner during instruction. For example, Gagne (1971) identified six important events of instruction: 1) gaining and maintaining attention; 2) insuring recall of previously acquired knowledge; 3) guiding the learning (by verbal or pictorial materials that provide "cues" or "hints" to new principles); 4) providing feedback to the learner on his accomplishments; 5) establishing conditions for remembering and transfer of learning; and 6) assessment of outcomes. The events identified by Gagne (reflecting the behavioral psychology background of Gagne) are in sharp contrast to the Starkweather (1970) list of stages in the teaching-learning process: 1) initial presentation; 2) student response; 3) evaluation of student response; 4) modified presentation possible to accommodate individual student needs; 5) collection of outcome data; 6) analysis of outcome data; and 7) redesign of teaching. Starkweather informally compared five teaching methods at each stage of a seven-stage teaching-learning process (Figure 1). Ranks were assigned in terms of relative merit at handling each stage and summed over seven stages resulting in a continuum from static to adaptive instruction.

Two research efforts have examined the two major elements in the interactive process--the tutor and the learner. Uttal, et al., (1970) adopted the human tutor as a model for developing a generative computer program for teaching mathematics:

> "We must always remember that the human tutor . . . is an analyzer and generator who determines what his student's needs are, and then from some general set of rules or heuristics formulates a sentence, a problem, a diagnostic, or a remedial unit. It is our premise that the best possible model we could use for the development of a computer tutorial situation is exactly this--the human tutor. The generative computer teaching machine quite explicitly models tutorial cognition by a human teacher.

Teaching Method

	Books	Lecture	Tutorial or small group	Noncomputerized programmed instruction	Computer-Assisted learning
1. Initial Presentation	Efficient maybe elegant (1)	Efficient maybe elegant (2)	Costly, maybe elegant (3)	Inefficient, few elegant examples (4)	Potentially as efficient and elegant as books & lectures since they may be used (1.5)
2. Student response	Un-programmed (4)	Un-programmed (4)	Optimal, but subject to un-programmed variations (1)	Limited (3)	Minimum limitations (2)
3. Evaluation of student response	None (5)	Limited to gross evaluation (restlessness, sleeping) (4)	Limited only by teacher's ability to divide attention (1)	Linear programs, student compares his response with answer(s) given; branching programs, some flexibility (3)	Substantial flexibility (2)
4. Modified presentation possible to accommodate individual student needs	No (4)	No (4)	Can be modified (1)	Linear programs, "tracking"; Branching programs, some modification (3)	Can be modified (2)
5. Collection of outcome data	Tests only (4)	Tests only (4)	Tests, teacher's memory of participation (3)	Recording of responses on paper (2)	Recording of responses in computer compatible form (1)
6. Analysis of outcome data	Typically, test statistics may be compared with those from other years, other courses, other schools (3)	(3)		Typically item statistics examined frequently during development. (2)	On line analysis possible (1)
7. Re-design of teaching	Select different book or revise (5)	Revise lectures for next year, or next week ([illegible])	Intuitive changes in course design. (3)	Revise program frames where difficulties have been pinpointed (2)	On line modifications could be built into system. Students can be prompted to "challenge" the program in order to improve it. (1)
Sum of ranks	26	25	15	19	10.5

Figure 1. Comparison of teaching method at each stage of the teaching-learning process (Starkweather, 1970, p. 355).

Figure 2 presents a model of the human teacher used by Uttal and his associates in developing their instructional program. This model contains as much or more detail on the processes of the "tutor" than any others I have found. Even at that, there is a need for further specificity in the model.

Looking at the other component of the tutorial interaction, i.e., the learner, DiVesta, et al., (1970, 1971a, 1971b, and 1971c) and summarized by DiVesta (1972) have identified the structure and relationships of the internal mental processing by learners (Figure 3) with detailed specification of both the analysis and synthesis stages based on empirical evidence.

The work by DiVesta in identifying processing stages within the learner provides a rich base of knowledge that adaptive instructional systems should take into account. Projecting from the characteristics of the learners to the instructional variables which should be incorporated in the tutor provides a flowchart incorporating the elements of Uttal and Divesta and is presented in Figure 4. Empirical studies will be required to further refine the model that is presented here.

The model was developed from the Uttal et al., (1970) and the DiVesta, et al. (1970, 1971a, 1971b, and 1971c) studies and from post-hoc intuitive analyses of tutor-learner interactions. The model attempts to make explicit the implicit decision-making process of a tutor when he is working with a learner. The tutor is composed of three elements: 1) response analysis component; 2) instruction generator; and 3) interface components. The learner is characterized by three elements: 1) the analysis stage; 2) the synthesis and storage phase; and 3) the interface component. The model is a closed-loop system, i.e., the processing could start at any point in the model and continue on through the model in a circular, self-adapting way much the same as the interaction between a student and a tutor.

The response analysis component receives a response from the student, analyzes the response, determines whether it is correct or not (C), and alters the processing of that student based on that decision. If an error is detected, an hypothesis about the cause of that error is generated (D) and a procedure for testing the error hypothesis is generated (E). The flow of activity then leaves the response analysis component and moves to the instruction generator. If the response analysis component had determined that the

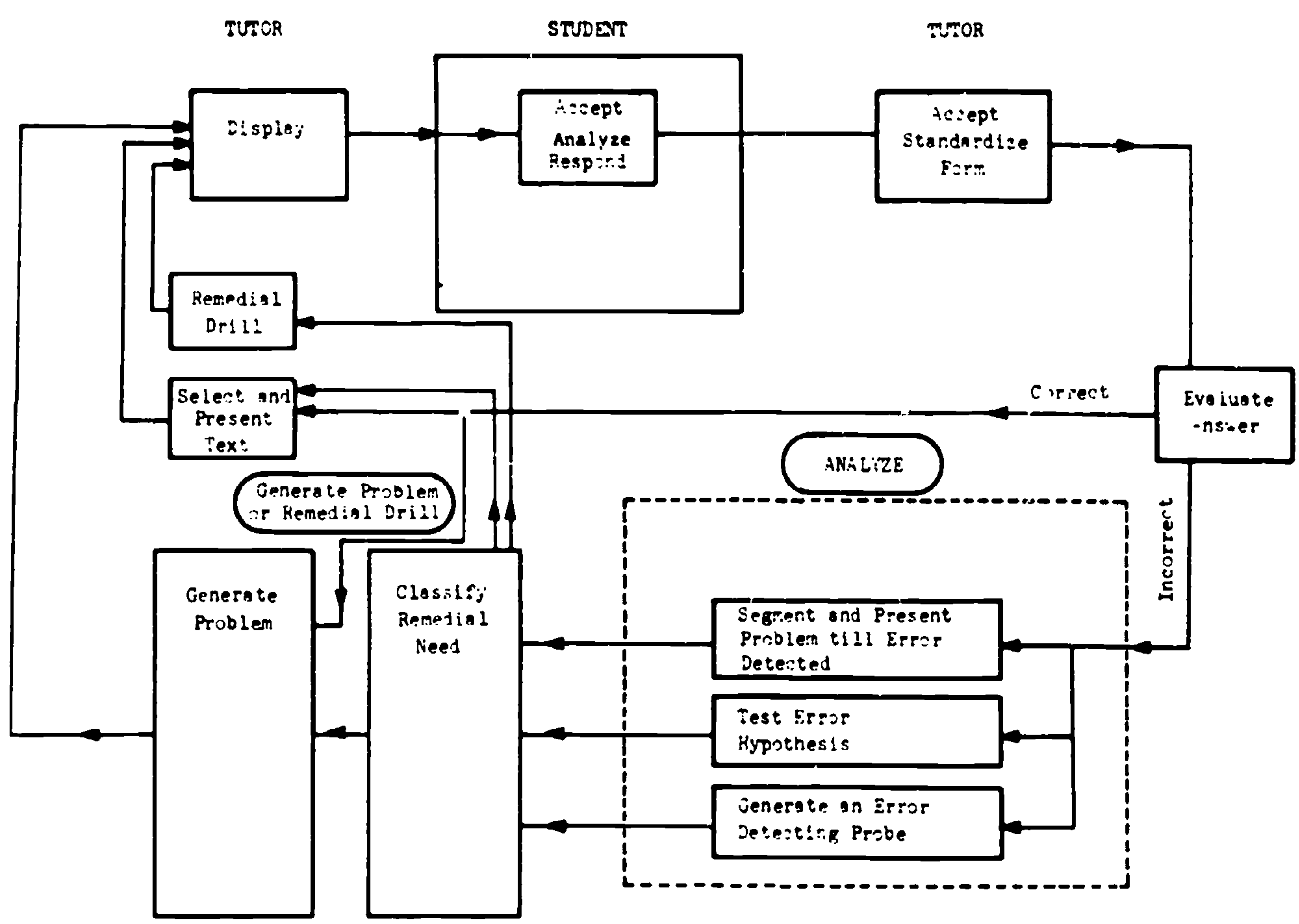


Figure 2. Model of the human tutor (Uttal, et al., 1970, p. 12).

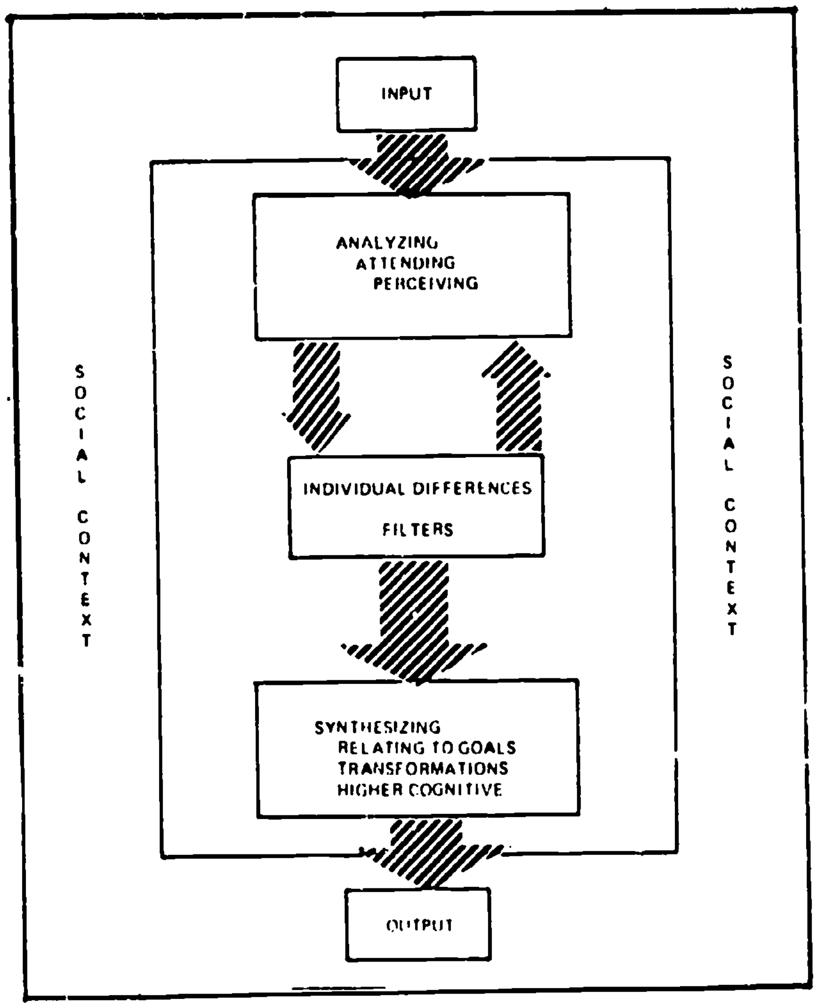
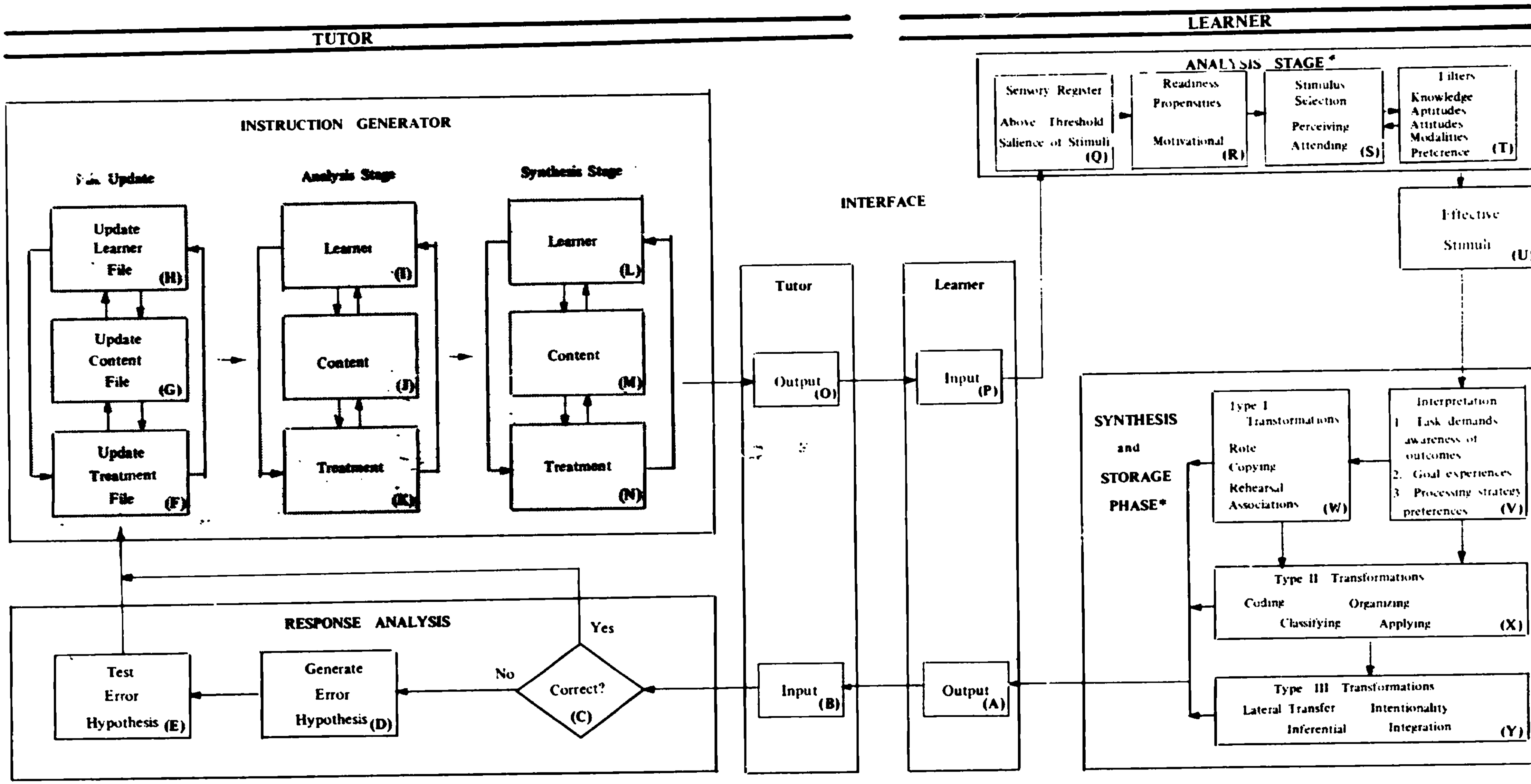


Figure 3. An overview of a model based on a dynamic view of instruction (Divesta, 1972, p. 36).



* From DiVesta, 1972, pp37-38.

Figure 4. Adaptive interactive instructional system

student response was correct, the flow of activity would leave the response analysis unit immediately from Block C and proceed to the instruction generator to prepare the next instructional material for the learner.

Files (records) regarding instructional treatment (F), content (G), and each learner (H) are maintained updated on the basis of each student's performance. The flow of activity between these three elements is shown to be circular and interactive to indicate that data is not presently available to tell us precisely how these files should be structured and how they interact with each other.

Based upon the DiVesta analysis of the processing done by the learner and his speculation that similar processing takes place in the instructor, the instruction generator contains an analysis stage and a synthesis stage. Within each of these stages three components must be considered: the learner (I and L), the content (J and M), and the treatment (K and N). Based upon data in the file update unit the instruction generator will analyze the learner, content, and treatment and pass that analysis on to the synthesis stage at which point specific instructional material will be generated for the learner. Again the flow of information within the instruction generator is shown as circular and interactive because of the lack of empirical data for stating otherwise. The newly generated instruction is then passed on to the interface unit which provides output to the learner.

Perhaps an example taken from the "mental processing" done by a tutor would be helpful:

> (C) Johnny did not correctly solve the equation $1/2 + 1/4 = \underline{\ \ ?\ \ }$. (D) Perhaps he did not convert both fractions to the same common denominator. (E) Have the learner convert a fraction from one denominator to another. The following conditions should be noted in generating the next instruction for him: 1) (H) he needs more help in converting to the lowest common denominator; 2) (G) the instructional material previously presented to him to teach conversion to common denominators was not satisfactory; and 3) (F) perhaps that conversion should be taught using visuals rather than relying on numeric symbols.

The structure and relationships of the internal processing by the learner have been explicated by DiVesta (1972):

"The model presented here and the considerations it highlights point to a sort of hierarchy of learning processes including attending, perceiving, discriminating, selecting and transforming. All of these are processes assumed to be essential facets of the learner's activities. Further elaboration of this model will require specification of stages that can be influenced by instruction and the kinds of instructional activities that are required to facilitate learning at each of these stages; a more complete specification, than is currently available, of the kinds and characteristics of instrumental activities in which the learner can engage at each stage of learning to reach specified terminal objectives; and a more detailed specification of the kinds of outcomes that can be expected at each of the phases described above. Some progress has been made in each of these areas, but further elaboration must depend upon additional empirical evidence (p. 39)."

In reviewing the attributes of effective learning environments developed by Gordon (1971) and Rosenshine and Furst (1971) it appears that this model approaches those requirements:

1. frequent and immediate feedback to pupils;
2. tutorial relationship;
3. individualized pacing;
4. individualized programing;
5. clarity of presentation;
6. variability in activities;
7. enthusiasm;
8. degree to which instruction was task or achievement oriented;
9. student opportunity to learn criterion material.

Further the system provides for "successive incremental improvements" (Glaser, 1972, p. 8) because all elements of the instruction including the tutorial interactions have been "captured" for future use, analysis, and "fine tuning." This is in contrast to traditional media and material where the stimulus presentation has been designed to present a predetermined content using a predetermined treatment designed to the needs of a predetermined "average" student.

Required Research and Development

The elements of the adaptive interactive instructional system itself suggests multitudes of research questions which must be answered. Any single block or component in Figure 4 needs further explication and exploration to determine specifically what its relationship is to other components in the

model, what its relationship is to tutors and learners, and what its relationship is to reality. We don't know enough about scope and sequence of content; characteristics of learners; design and validation of instructional strategies; interaction effects of learners, content, and treatments; evaluation of student responses; procedures for modifying presentations; and identification of appropriate data for modifying the system--to name just a few of the variables. Programatic research efforts will be required to identify the appropriate variables and relationships and incorporate them into a single adaptive interactive instructional system which can have widespread application for the education of our children. Goodlad (1968) summarized the research challenge quite well:

> ".. .The research challenge is to catalog those aspects of instruction that are most appropriate for the machine teacher, on one hand, and for the human teacher, on the other. We must not make the human teacher a supervisor or coordinator of the computer or he will become a servant. The teacher may very well contribute to programming, but the interface should be between student and machine. For us to take our traditional position with respect to this electronic teacher is to delay advance in the instructional process and, in the long run, to endanger the highly relevant role of the human teacher (p. 10)."

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